THE JPL DEEP-WELL MID-INFRARED ARRAY CAMERA

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Abstract. We descri ibe **the** development **of a** mid-infrared **camera** intended **for use at the** Palomar 5-m telescope and **at the NASA** Infrared Telescope **Facility.** The **camera is** based on Rockwell's HF-16 **128x128** Si:As BIB **array.** This **anay** is unusual **in** that **it** has **a well** depth **of** approximately **30** million electrons; **this will allow the** use **of** traditional broadband astronomical **filters (N** and **Q)** while keeping **a reasonable field-of-view.** Measured arr ay performance indicates **that it** has a read noise **of** 1100 **electrons** and **shows** non-linearities **of** < 10/0 **up to** 65% **of full well.** In this **paper, wc discuss the array and its** operating characteri stics **and wc give a brief overview of the** camera design.

1. Constraints **of the Environment**

One of the most important requirements of a ground-based, mid-infrared **(5- 25 pm)** array camera is its ability to cope with the large number of background photons which flood its pixels. This abundance of photons has been handled in three ways: 1) ultra-fast readout rates; '2) very narrow filter passbands; and/or **3)** very small platescales. The first method is unattractive because of th c high cost and com plexity involved in fast readout electronics and data storage devices. The second and third are u nattractive because more on-source integration time is required to reach a given sensitivity, aud the third also reduces the Iicld-of-view. A ncw alternative is to usc a detector array which has much deeper wells, allowing the use of normal electronics without sacrificing the broad filter passbands.

MIRLIN, a mid-infrared large-well imager under development at JPL, provides a simple, portable, and cost-effective observing environment which takes advantage of recent developments in deep well array technology. Wc will be able to take data with a **128x128** array with up to a 1 arcminute field-of-view in the broadband N and Q filters, a mode which has not been feasible until now. Usc of the Q filter will require that we read the array in less than 4 ms- difficult, but well within the constraints of modern technology.

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2. Detector Characteristics

MIRLIN is a unique instrument for ground-based 5-25 μm astronomy primarily because of the unusually large full well depth of the detector array. The array is a "High Flux" 128×128 arsenic-doped silicon blocked impurity band (Si:As BIB) detector array (designated HF-16) manufactured by Rockwell International. The bias across each pixel is held constant by a direct injection FET while the current is integrated on a 1.7 pF capacitor; the voltage across this capacitor is buffered by FET source-followers which have a net gain of 0.77 (Figure 1 a). The full well voltage swing at the output is approximately 2.2 V, implying a detector full well depth of 3×10^7 e$^-$, roughly an order of magnitude deeper than previously available detectors. This depth allows longer integration lengths before the array saturates on the background- reducing the speed requirements of the support electronics and/or allowing the use of wider fields-of--view or wider filter passbands.

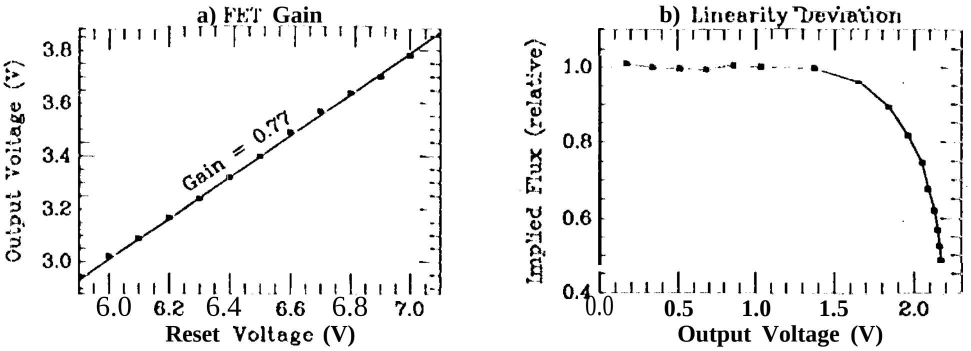

Fig. 1. Measured FET gain and linearity of the Rockwell HF-16 array. Figure 1a shows the variation of the output voltage when the direct injection FET is pinched off and the reset voltage is varied. Figure 1b shows the variation of the measured "flux" (signal/integration length) as a function of the final signal level.

This array has a read noise measured at about 1100 electrons at low background conditions (109 ph/s/cm^2). The high noise value is a result of the large capacitance needed to provide a deep well and cannot be reduced by correlated sampling due to the multiplexer design, but this is not detrimental as the device will still be easily background-limited at a well depth of just a few percent. The response uniformity and linearity are also very good for this array. Rockwell has measured the uniformity of our array to have 1 σ deviations of approximately 2.8%, and we have measured the response of individual pixels to be linear to 1% up to 1.4 V (65% of the full well 2.2 V- Figure 1 b). Such characteristics reduce the amount of post-processing needed to assess the data- particularly important when decisions must be made quickly while observing at the telescope and allow the overall quality of the data to be higher since the error terms are smaller.

3. Camera Design

Our design goal is to have a compact, simple camera which delivers diffrac-t,ion-limited images from 7 to 25 μm and which may be used at the Palomar 5-m or the IRTF without moving or replacing the optic-s or the detector array. We have the following basic requirements: simultaneous wavelength c.overage from 5-25 μm, and Nyquist-sampled spatial resolution for $\lambda > 7.5$ μm at Palomar, and for $\lambda > 15$ μm at the IRTF- the field-of-view resulting from this requirement is 20"x 20" at Palomar and 1' x 1' at "the IRTF. We have chosen the simplest optical design which meets these requirements: one aspheric camera mirror, a flat fold mirror, and a plano-convex CdTe lens at the pupil. This design requires only that the pupil diameter be c.hanged when moving the camera between tclcsc.opts.

The dewar uses conventional infrared system design. The optics and detector are mounted on the work surface of a 10 inch diameter Infrared Laboratories (Tucson, AZ) LHe/LN_2 dewar with the entrance window located on a, side wall. Uplooking or sidelooking operation is allowed by locating the cryogen fill tubes just inside the vacuum jacket on the same wall as the window and using tubes that extend to near the bottom of the cryogen cans. Stepper motors control the positions of the two filter wheels, and limit switches allow the accurate initialization of their positions.

The electronics wc have chosen are based on the coadding DSP design currently in usc at the NASA IRTF for their 256x256 InSb facility camera (N SFCAM, scc Shu re *et* al. in these proceedings) and are available from Advanced 1)esign Systems (Mililani, HI). The chief differences arc the increased number of output channels (16 vs. 4) which must be handled and the usc of 14-bit A/D converters as opposed to 16-bit. Noise analysis shows that 1 4-bit resolution is adequate to sample the noise floor while still covering the entire dynamic range of our array.

4. Performance Estimates

Because the system is still being assembled, wc can only estimate its performance at this time. Wc do this by first calculating the background generated by the telescope and sky assuming a tempera.tulc of 275-280 K and an emissivity of 15- 20%. We next compute the flux a star spread over several pixels of the array must produce in order to be detectable at a 1 σ level over this background in a single 1 second image. The limiting flux (photons/see) of a point source for a BIB array is given by $n_{obj} = S/N\sqrt{N_{pix} n_{back}/(t_{int}\frac{\eta}{\beta})}$ where S/N is the signal-to- noise ratio, N_{pix} is the number of pixels, n_{back} is the background photon flux pcr pixel, t_{int} is the integration length, and η/β is the detective quantum efficiency of the detector (taken to be η ~/1.15 at 1- '2 V biases). A fcw examples of the 1σ/1s limiting flux arc given in ~'able I, along with filter data, detector quantum yield, and the integration length at which the detector wells will be 1/2 full from the background.

TABLE 1
Estimated Performance

λ (μm)	$\Delta\lambda$ (μm)	τ_{Filt}	$(\eta G)_{Det}$	Palomar (0.15 ''/pix) Time to 1/2 Well (ms)	Palomar (0.15 ''/pix) 1σ/1s Lim Flux (mJy)	IRTF (0.5 ''/pix) Time to 1/2 Well (ms)	IRTF (0.5 ''/pix) 1σ/1s Lim Flux (mJy)
4.72(M)	0.55	0.90	0.15	7100	9.0	290	13
10.27	1.01	0.86	0.40	95	40	35	74
10.30 CVF	0.10	0.40	0.40	2000	180	730	340
11.00 (N)	5.78	0.88	0.40	16	18	5.9	35
19.76	1.72	0.32	0.53	130	110	46	250
21.17 (Q)	11.00	0.60	0.53	11	37	3.9	82
24.49	0.72	0.25	0.48	600	270	210	600

Other filters: 7.91(0.76), 8.81 (0.87), 9.82(0.92), 11.70(1.11), and 12.49(1.16) μm–performance similar to the 10.27(1.01) filter; 18.10(1.64) and 21.17(2.25) μm– performance like the 19.76(1.72) filter; and a 7-14 μm CVF– from which the 10.30(0.10) entry is derived.

5. Future prospects

The most exciting prospect in improving this system is incorporating a larger array. A 256x256 device would potentially allow us to image 4 times the area in a single frame without sacrificing resolution; however, a device with a proportionally deeper well would be needed to allow the same per-pixel readout rates without saturation. Multiplexers with > 60 million electron wells have already been demonstrated by several vendors, and it is conceivable that a 2.56X256 device with 108 electron wells may become available in the next few years. Alternatively, a small-well array with on-device background suppression could be developed. Testing with visible wavelength devices at JPL (B. Pain, private communication) indicates that factors >100 in background reduction can be achieved, at the expense of increased noise. This technique has an added advantage in that non-uniformity is correspondingly reduced. While large mid-IR arrays based on this technology are farther off, they provide an interesting additional possibility.

Acknowledgements

We would like to thank David Seib and Michael Salcido of Rockwell for pointing out this array to us and for their assistance in getting it operational as quickly as possible. We also thank Don Ritchie's Infrared Detector Group at JPL for their assistance in lab tests of the array. This work was performed at the Jet Propulsion Laboratory, California Institute of Technology, under contract with the National Aeronautics and Space Administration.